Development and Application of a Child Restraint System Model for Safety Performance Assessment

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Introduction

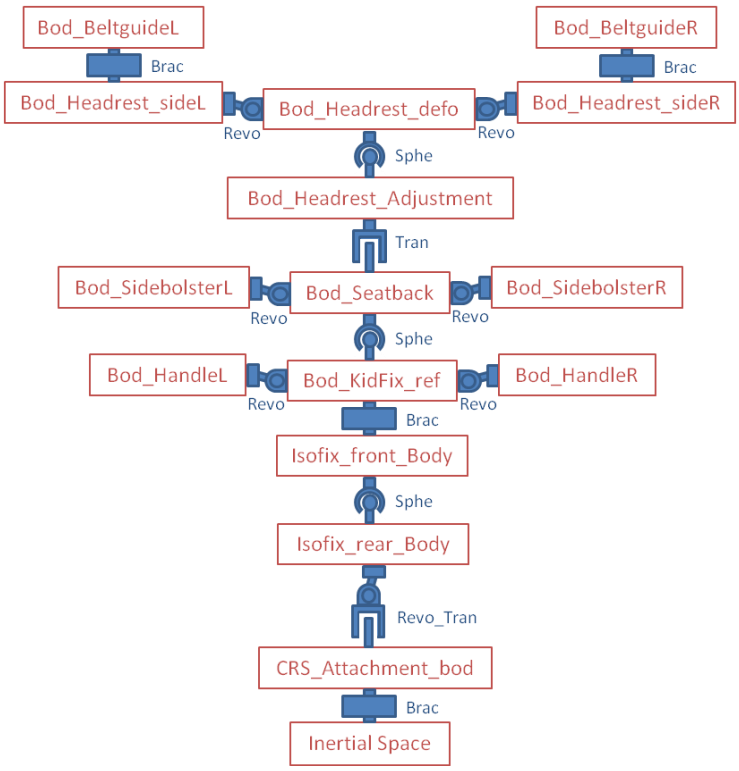
Peugeot Citroen Automobiles (PSA), Britax-Römer (Britax) and TNO Automotive Safety Solutions (TASS) have co-operated in constructing and validating a numerical model of a group 2/3 child restraint-system (CRS), the KidFix from Britax, see Fig. 1.

The objective of the project was to develop a virtual CRS model that is validated against frontal and side impact load cases with a seated six year old child occupant. The child occupant is represented by the MADYMO Q6 child dummy model, which was developed by TASS in co-operation with PSA and released in MADYMO version 7.3. The simulation results of the CRS model and Q6 child dummy have been verified on their ability to adequately predict trends and injury values when loaded in a full vehicle model environment.

Figure 1: Britax-Römer Kidfix

Model Creation

A MADYMO Multi-Body model, representing the KidFix child seat is created, using MADYMO version v7.3 [1]. The Body and Joint structure tree is shown in Fig. 2. Based on engineering judgment, bodies and restraints are selected to represent all the relevant deformation modes of the CRS.



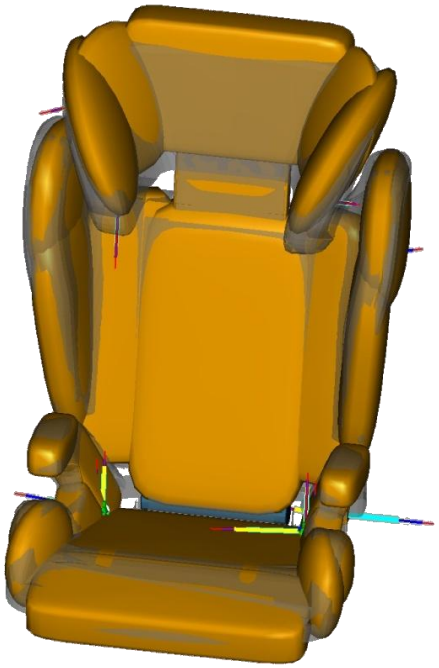


Figure 2: Tree structure of KidFix MADYMO model.

The Ellipsoids representation of the KidFix child seat surface is created using a PSA CAD model, where the ellipsoids are scaled and positioned to match as close as possible the seat surface, see Fig. 2). The Joint locations, body CoG locations and masses are retrieved from measuring a physical seat and tested seat components, as well as from observation of the test movie and pre and post test pictures.

Characterisation of the seat

In order to define the characteristics for the joint and contact stiffnesses of the MADYMO CRS model, a series of component tests was performed on production models of the KidFix child seat. The test set-ups are shown in Fig. 3. All the proposed component tests have been performed at TTAI crash laboratory in Helmond, the Netherlands. Subsequently, 11 simulation models are built to represent an identical set-up as the corresponding component test. For each of them, the particular boundary conditions used in the component test are reproduced, and the impactor positioning and kinematics are simulated.

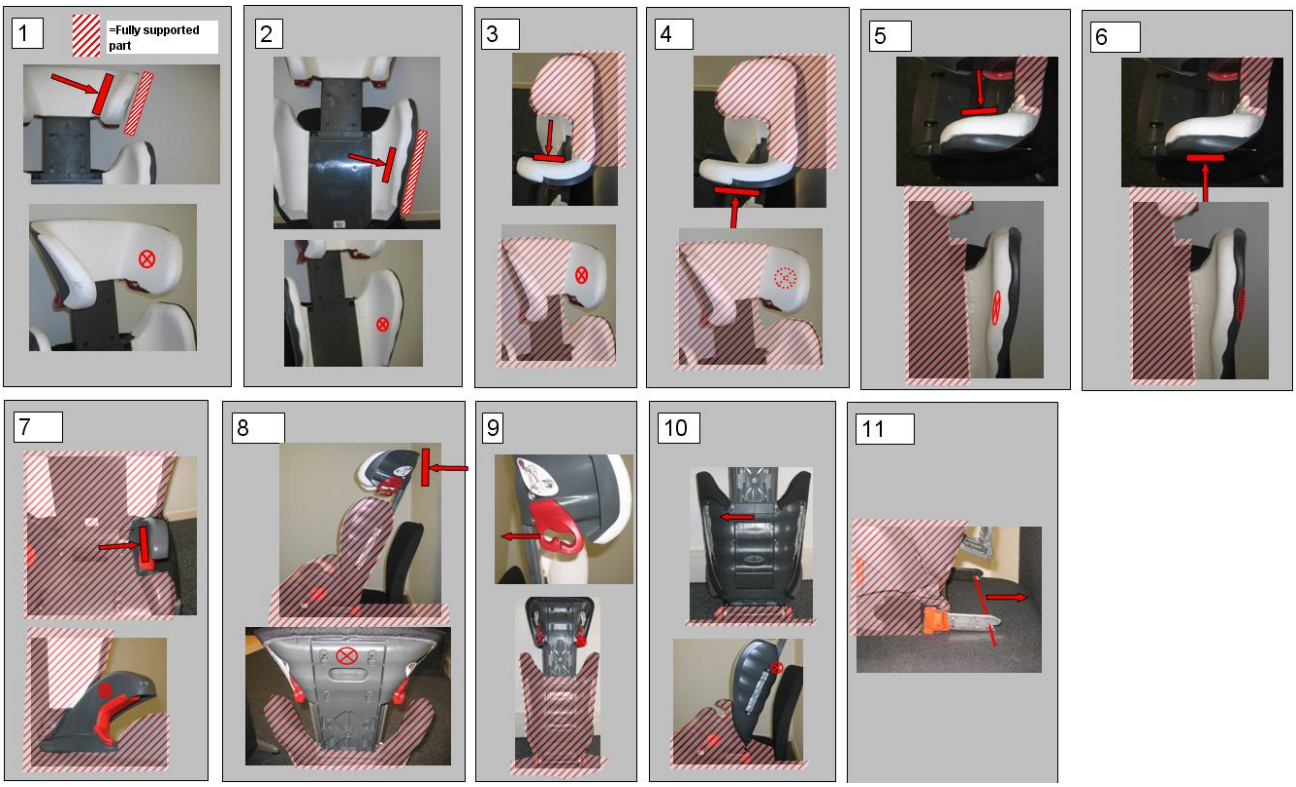


Figure 3: Component Tests Set-up

Model Validation

In order to validate the KidFix child seat model, the model is used in a series of sled tests that are correlated to the Römer sled test results. The test series includes both frontal impact direction as well as lateral impact direction.
For the sled test validation simulations, a beta version of the Q6 ellipsoid dummy is used, which closely matches the final released Q6, see Fig. 4a). The dummy is positioned into the KidFix child seat model and a 3-point belt system is positioned over the seat and dummy model, as shown in Fig. 4b.

Figure 4a: Q6 ellipsoid model

Figure 4b: Q6 model in KidFix child seat model

The frontal impact test set-up used for this validation is a standard ECE-R44 setup.
The KidFix seat is attached to the bench of the ECE-R44 sled using the ISOFIX fixation and the 3-point belt system. The tests are performed at two different impact velocities: 50 km/h and 40 km/h. Each test is repeated three times.

Two different set-ups are used for the lateral test validation. The first set-up is a 25 km/h lateral impact, including a rigid plate to represent the side door. The dummy is seated in the CRS against the struck side door, see Fig. 5 left).
The second set-up is a 41 km/h impact, without any door-panel, to represent a dummy that is not seated on the struck side of the vehicle (see Fig. 5 right). Significant swing motion of the CRS and the dummy is expected here.

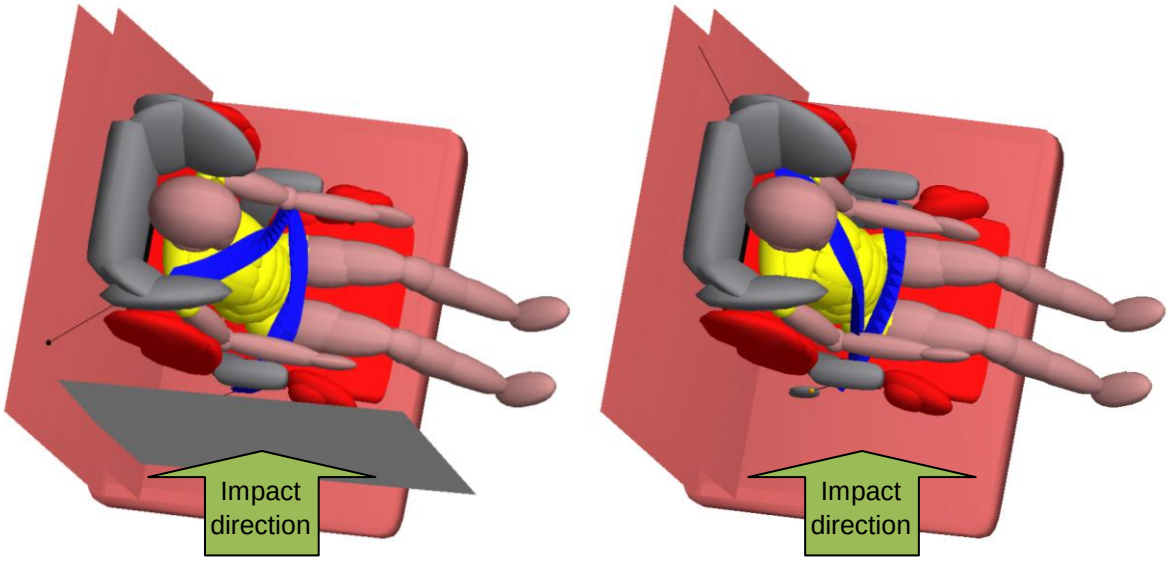


Figure 5: Test set-ups for Struck side and non-struck side impact directions

Based on careful analysis of the sled test videos, the correlation of the model against the actual sled tests is improved by adapting the following parameters:

- The characteristics of the seat belts used in the sled test series are not known. Therefore the material stiffness is used as a tuning parameter. It is assumed that no retractor is present and belt material characteristics are estimated to closely match the kinematics of the Q6 in the test.
- Material characteristics and property of the sled seat cushion FE model (loading characteristic, membrane thickness) are estimated to closely match the forward pitching motion of the CRS.
- Some flexibility is added to the Isofix Fixation in Y- and Z- rotation direction, in order to allow the CRS to flex in roll and yaw direction.
- The contact stiffness property and the Headrest Z- direction deformation stiffness of the KidFix CRS model have not been defined by component tests and were modelled using a generic characteristic.

Results

In general, the results of the frontal impact simulations show good correlation with the actual test results, as summarised in Tab. 1 and Tab. 2. Good correlation is observed for the Thorax and Pelvis resultant accelerations shown in Fig. 6 and Fig. 11 as well as for the Thorax deflection shown in Fig. 10. The rebound in the seat is causing a peak in the Thorax simulation results around 170ms. The values in Tab. 1 and Tab. 2 for the Thorax vertical 3ms acceleration levels are calculated from the positive vertical acceleration only. The vertical Thorax acceleration signal, as shown in Fig. 7, also shows a large negative peak. The simulation predicts this trend well. The Neck tension forces correlate well with the test results, as shown in Fig. 8, but the Neck torque moment does not correlate as good as the rest of the signals.

Table 1: 40km/h frontal impact injury results.

Injury	Test 111905	Test 111906	Test 111907	Simulation
Head X Displacement (mm)	*390*	*390*	*390*	*387*
Thorax Resultant 3ms Acc. (g)	*33.5*	*33.9*	*33.3*	*31.9*
Thorax Vertical 3ms Acc. (g)	*10.3*	*8.8*	*9.3*	*9.0*
Neck Tension Force (N)	*1920*	*1855*	*1965*	*1981*
Neck Torque My (N)	*47.4*	*43.8*	*42.0*	*28.2*
Thorax Deflection (mm)	*27.8*	*27.7*	*30.6*	*27.1*
Pelvis resultant 3ms Acc. (g)	*31.1*	*33.0*	*33.1*	*30.1*

Table 2: 50km/h frontal impact injury results.

Injury	Test 103208	Test 103209	Test 103210	Simulation
Head X Displacement (mm)	*400*	*390*	*400*	*429*
Thorax Resultant 3ms Acc. (g)	*35.4*	*34.2*	*34.9*	*33.4*
Thorax Vertical 3ms Acc. (g)	*10.6*	*10.9*	*10.4*	*7.8*
Neck Tension Force (N)	*2674*	*2742*	*2733*	*2253*
Neck Torque My (N)	*45.0*	*44.1*	*42.6*	*26.1*
Thorax Deflection (mm)	*35.4*	*33.9*	*34.4*	*32.5*
Pelvis resultant 3ms Acc. (g)	*34.2*	*35.8*	*35.3*	*36.0*

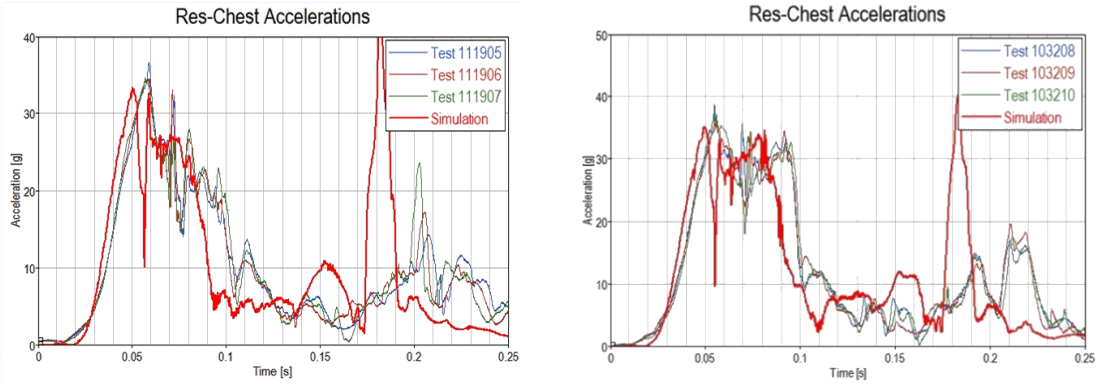


Figure 6: Thorax Resultant accelerations in the 40km/h & 50km/h frontal impact.

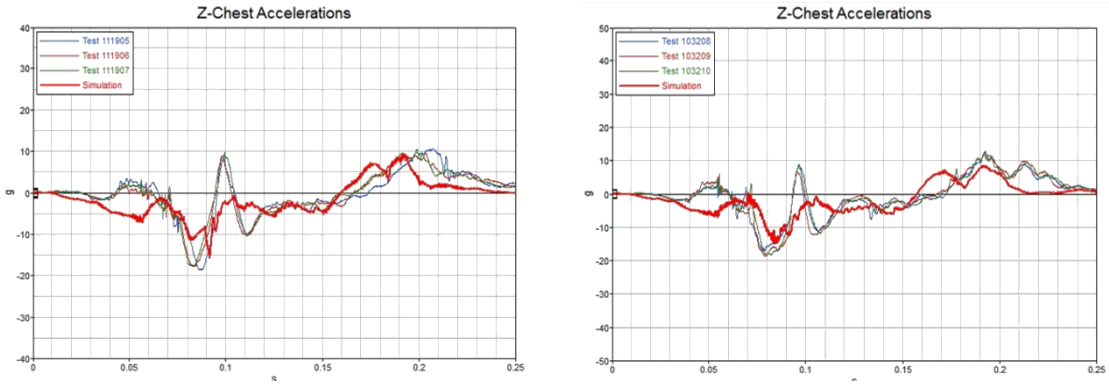


Figure 7: Vertical Thorax accelerations in the 40km/h & 50km/h frontal impact.

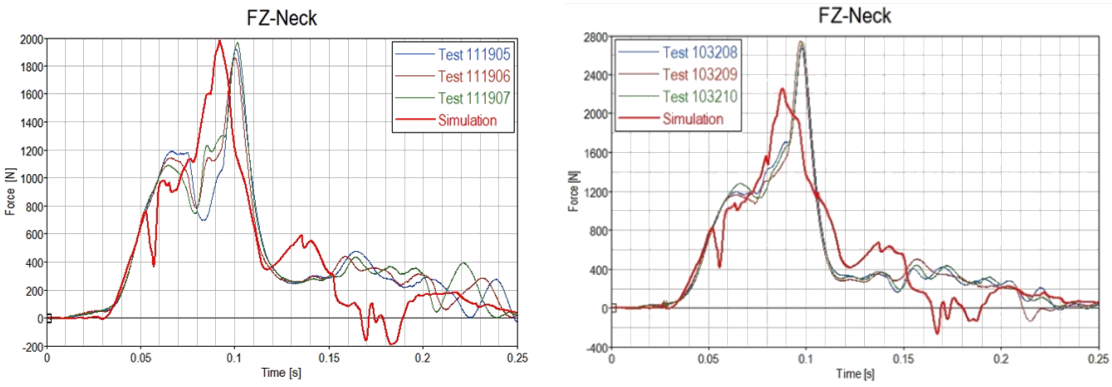


Figure 8: Neck Tension forces in the 40km/h & 50km/h frontal impact.

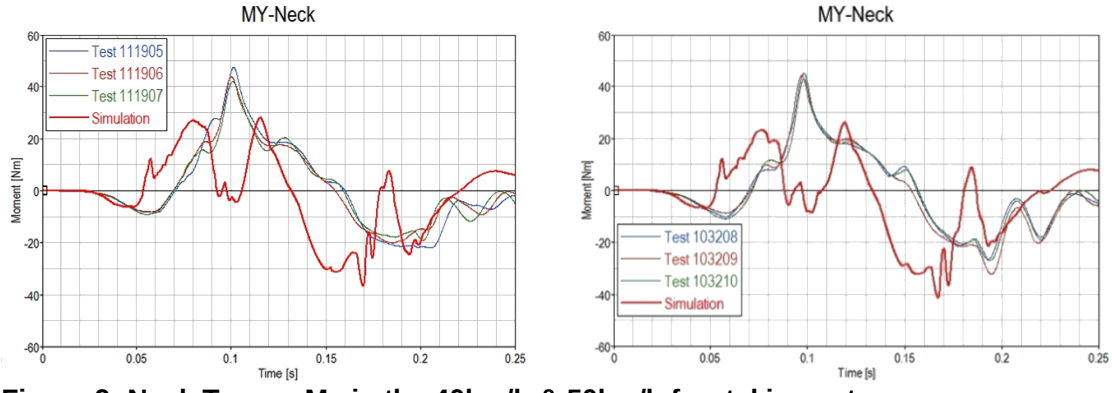


Figure 9: Neck Torque My in the 40km/h & 50km/h frontal impact.

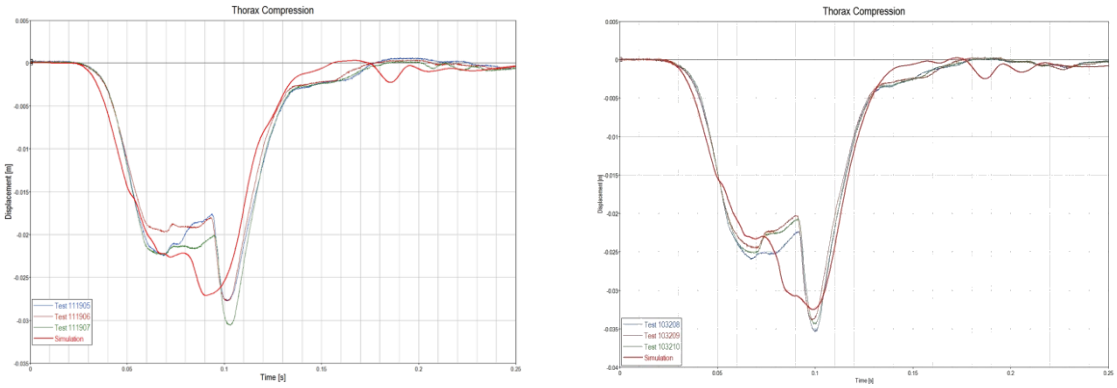


Figure 10: Thorax Deflections in the 40km/h & 50km/h frontal impact.

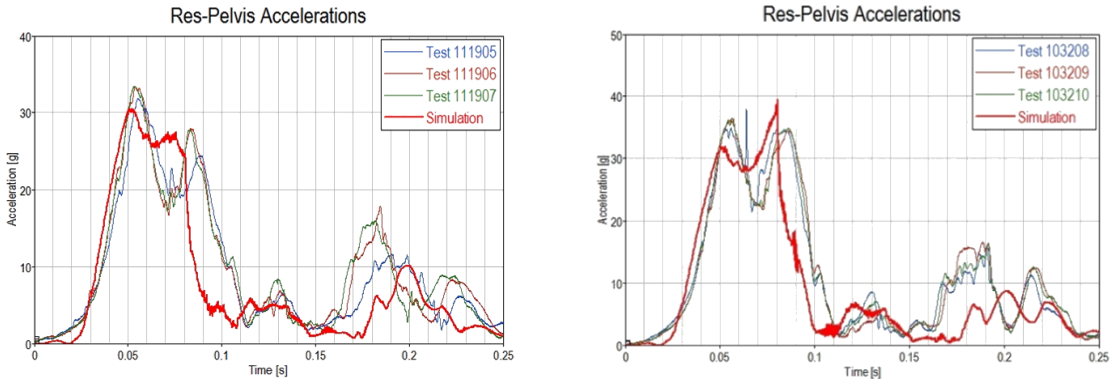


Figure 11: Pelvis Resultant accelerations in the 40km/h & 50km/h frontal impact.

Results for TASS

As illustrated in Fig. 12 on the left, in both frontal impact simulations it is observed that around 50ms a contact of the dummy spine with the back of CRS seat is causing a disturbance in the head and chest accelerations. Around 70ms the dummy's lower legs stretch towards their maximum forward bending position, see Fig. 12 on the right, causing a high peak force in the femurs as a result of the bottoming-out of the knee joint. These issues were communicated to the TASS dummy development team and improvements to the Q6 dummy model were made and incorporated in the MADYMO version 7.4 release [2]. This illustrates that the co-operation between OEM (PSA), Tier1 (Britax) and TASS benefits all parties and results in better projects and improved products.

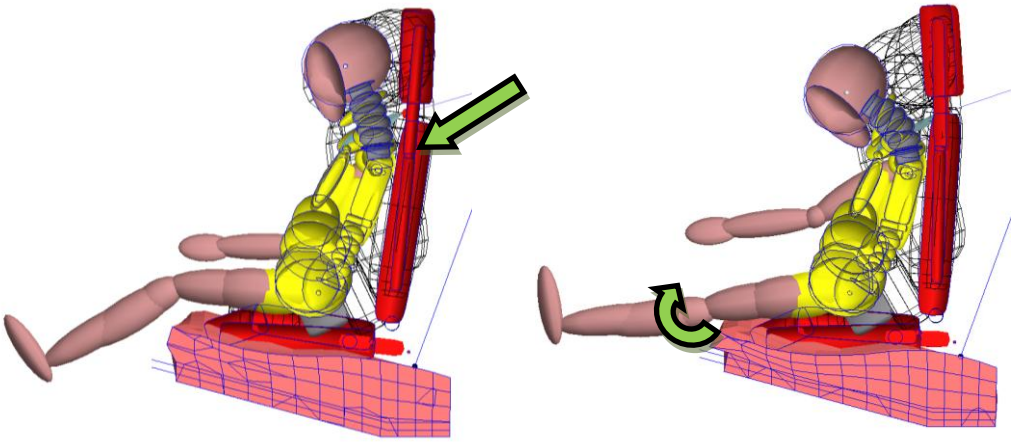


Figure 12: Spine-Seatback contact at ~50ms and knee locking at ~70ms.

In both frontal impact simulations it is found that the rebound of the dummy, back into the seat occurs sooner and faster compared to the rebound observed in the test videos. Further investigation is needed to clarify the cause of this. Possible causes are the (unknown) belt characteristics and/or the joint unloading characteristics in the Q6 dummy spine joints which may be acting too elastic (requiring more hysteresis or damping). The longitudinal Neck forces are found to be over-predicted for these simulations. The cause for this behaviour may be related to the sooner and faster rebound behaviour.

Side impact simulation results

The simulation results of the side impact tests correlate well with the sled test results, as shown in Tab. 3, Tab. 4 and Figs. 13–17. The correlation of the 41 km/h non-struck side test is not as good as for the 25 km/h struck-side test, although the kinematics look very similar to the actual sled test, as shown in Fig. 18 and Fig. 19. The high severity impact conditions of this test set-up almost cause the dummy to eject from the CRS and a lot of discreet events and initial conditions affect the results of this test. This is also illustrated by the spread in the results of the sled test series.

Table 3: 25km/h struck side door impact injury results.

Injury	Test 104507	Test 104508	Test 104509	Simulation
Head resultant 3ms Acc. (g)	*62.8*	*66.6*	*62.0*	*61.9*
Neck Tension Force (N)	*1489*	*1422*	*1463*	*1413*
Neck Torque Mx (N)	*11.3 / -22.8*	*10.0/-28.9*	*10.1/-29.5*	*9.6/-22.5*
Thorax Deflection (mm)	*5*	*5*	*5*	*5*
Pelvis resultant 3ms Acc. (g)	*28.8*	*28.6*	*28.3*	*32.1*

Table 4: 41km/h non-struck side impact injury results.

Injury	Test 104510	Test 104511	Test 104512	Simulation
Head resultant 3ms Acc. (g)	*35.6*	*35.3*	*35.2*	*26.0*
Neck Tension Force (N)	*921*	*1018*	*831*	*542*
Neck Torque Mx (N)	*6.1/-31.0*	*8.5/-28.4*	*6.6/-34.6*	*6.2/-29.2*
Thorax Deflection (mm)	*9*	*11*	*10*	*8*
Pelvis resultant 3ms Acc. (g)	*36.1*	*36.9*	*34.6*	*41.7*

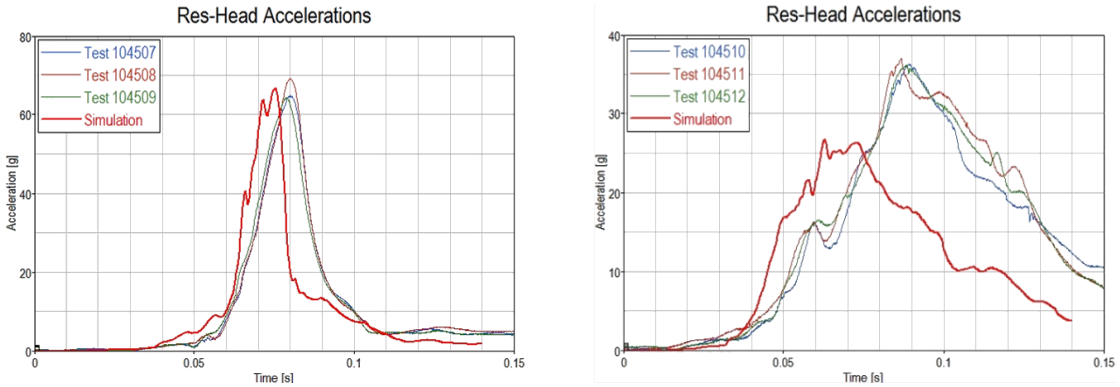


Figure 13: Head Resultant accelerations of 25km/h and 41km/h side impact.

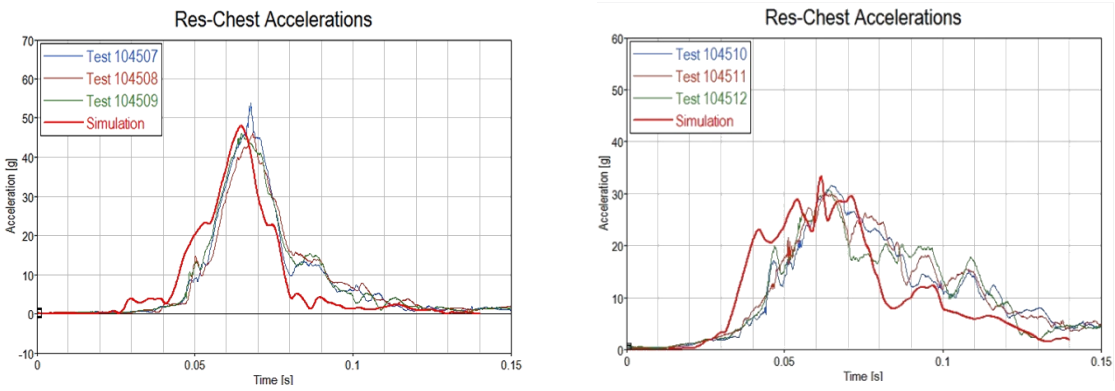


Figure 14: Chest Resultant acceleration of 25km/h and 41km/h side impact.

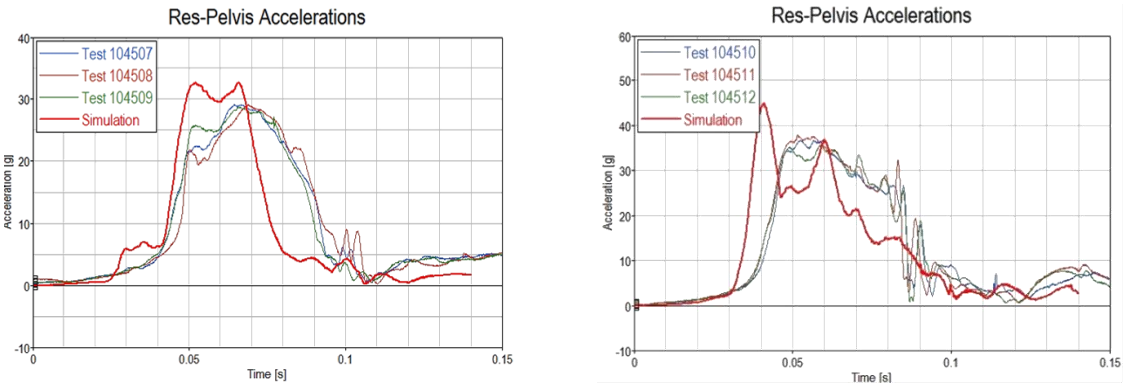


Figure 15: Pelvis Resultant acceleration of 25km/h and 41km/h side impact.

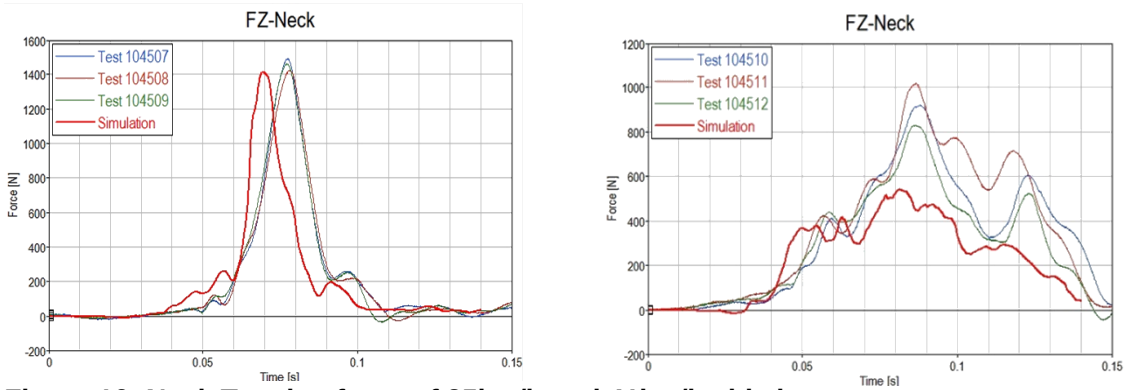


Figure 16: Neck Tension force of 25km/h and 41km/h side impact.

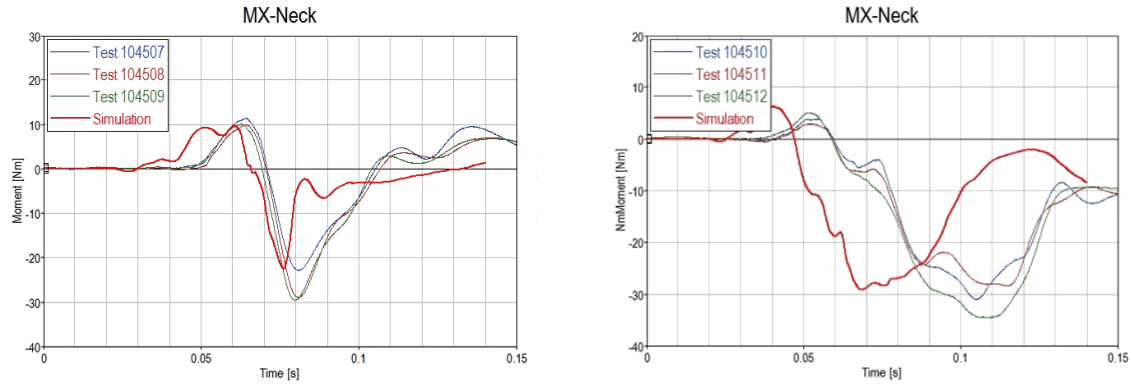


Figure 17: Neck Torque Mx of 25km/h and 41km/h side impact.

Figure 18: 25km/h lateral impact, struck-side, T=100ms.

Figure 19: 41km/h lateral impact, non-struck-side, T=100ms.

Conclusions

PSA, Britax and TASS co-operated to create a MADYMO model for the Römer KidFix Child restraint seat. The KidFix model is characterised using a series of component test results and validated against a sled test series with four different test set-ups.

The correlation of the MADYMO simulations with the KidFix CRS against the actual sled test series shows that the CRS model is robust and responds realistically and predictably.

The new MADYMO Q6 ellipsoid child dummy model that is used for this validation shows overall a good correlation with the test results. The collaboration between the OEM and the Software developer has not only lead to a validated CRS model, but also to development improvements in the used Q6 dummy model.

Literature

[1] MADYMO Reference Manual V7.3, Nov.2010, TNO Automotive Safety Solutions.
[2] MADYMO Release Notes V7.4, 2011, TNO Automotive Safety Solutions.